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# Role of renewable energy investment in India: An alternative to $CO_2$ mitigation

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ABSTRACT

This paper discusses the potential of renewable energy, investment and $CO_2$ mitigation by renewable energy technologies. Currently, India's per-capita emissions are around one tonne of $CO_2$/year. The present energy scene offers India a window of opportunity to invest in renewable energy. The annual turnover of renewable energy industry has reached $12.3 billion in 2011, which is 36% higher than 2010 investment of $7.5 billion. Increasing the share of renewable energy in overall energy mix is an effective option to mitigate $CO_2$ emission. Presently, the share of renewable energy is around 12% in the energy mix. The present study estimated $CO_2$ mitigation potential of Indian renewable energy sector about 203 million tonnes with an installed capacity of 24 GW in 2012. However, enormous potential identified in renewable energy sector with favorable $CO_2$ mitigation the government is compromising with limited financial resources. However, policy efforts need to be strengthened to encourage a massive scale-up of renewable technologies to build sustained low carbon economy.



**Contents**



## 1. Introduction

The current population in India is more than 1.22 billion [1] and arise at an annual rate of 1.58% accounts 17.31% of the world population has unquenchable thirst for energy. Table 1 presents

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the current and future projected requirements of energy in India. India is experiencing foremost shortage of electricity [3] generation capacity as illustrated in Table 2. It needs an investment of at least $135 billion to provide universal access of electricity [4] for its population. However, Fig. 1 shows the overall $CO_2$ emissions have been increasing gradually from 1900 to 2010. Further, this expected to increase sharply in the next 20 years while India will enter [5] sustainable economic growth. About 70% of entire Greenhouse Gas (GHG) emissions in India [6] related to energy, mainly from combustion of fossil fuels for electricity generation, heat and transportation whereas power sector alone accounts for more than 50% of these overall $CO_2$ emissions.

Presently India is experiencing two challenges; one is to meet the energy demand through fossil fuels for its economic growth and other is to cut $CO_2$ emissions; nevertheless, it cannot do both. Consequently, there is a need to solve the dilemma by alternate way of energy sources. India is endowed with vast [8] renewable energy potential such as, wind (45,000 MW), solar (50,000 MW), small hydro (15,000 MW) and biomass energy (30,000 MW), this imaginable source of energy can congregate all the future energy demand. On the other hand, promotion of alternate fuel plays a vital role to mitigate the $CO_2$ emission and favor economic growth. To cut down the world $CO_2$ emissions from 42–39 Gt, accordingly the worldwide investment in renewable energy sector assets would raise from $100 to 500 billion during 2010–2030. Thus, heavy investment would be required for clean energy services. To meet the increasing energy demand and sustainable economic growth India decided to promote alternate fuel funding in the recent years. In this context, the present article elaborated the renewable energy investment in India in the categories of wind, photovoltaic energy, concentrating solar thermal power, solar hot-water system, biomass power and heat, bio fuels, small hydro-power (SHP), and geothermal energy.

**Table 1**
Projected energy requirements (MTOE).
*Source*: [2].

| Year | Hydro | Nuclear | Coal | Oil | Nat. gas | Total |
|---|---|---|---|---|---|---|
| 2011–2012 | 12 | 17 | 283 | 186 | 48 | 546 |
| 2016–2017 | 18 | 31 | 375 | 241 | 64 | 729 |
| 2021–2022 | 23 | 45 | 521 | 311 | 97 | 997 |
| 2026–2027 | 29 | 71 | 706 | 410 | 135 | 1351 |
| 2031–2032 | 35 | 98 | 937 | 548 | 197 | 1815 |

**Table 2**
The demand and supply of power in India for the year of 2012.
*Source*: [3].

| Energy | | | | Peak energy | | | |
|---|---|---|---|---|---|---|---|
| Demand (MW) | Supply (MW) | Deficit (MW) | Deficit (%) | Demand (MW) | Supply (MW) | Deficit (MW) | Deficit (%) |
| 933,741 | 837,374 | 96,367 | 10.3 | 136,193 | 118,676 | 17,517 | 12.9 |

## 2. Indian power scenario and $CO_2$ emissions

The overall electricity consumption in India is quite low. The per-capita electricity consumption is about 778 kWh/year [3] with urban-rural disparities. About 65% of the population of India live in rural areas and consume only 30% of electricity and their counterparts enjoying the remaining 70%. The energy gap between demand and supply for 2012 reached almost 96.36 GW which is 10.3% of the total demand as reported in Table 2. The peak demands deficient more than 17.51 GW, corresponding to a shortage of 12.9%. India needs [9] more than double of its current installed capacity to over 300 GW by 2017 to provide adequate electricity to its population.

Currently, Indian per-capita emissions are around one tonne of $CO_2$/year [9]. The trend in $CO_2$ emissions presented in Fig. 1 by IEA (International Energy Agency), 2011 since 1990–2010. The worldwide per-capita is 4.2 t with most industrialized countries emitting 10–20 t/person/year. Nevertheless, because of its large population, India contributes now around 5% to worldwide [7] $CO_2$ emissions. Fig. 1 proved that the $CO_2$ emissions have nearly tripled between 1990 and 2009. The major source of $CO_2$ emission caused in India by coal based power plants, which represented 54% of $CO_2$ in 2009, up from 40% in 1990 Fig. 2. India generating 67% of electricity from coal in 2012, another 19% from hydro, 12% from renewable energy sources and remaining 2% from nuclear [3] as shown in Fig. 3. Besides, India aims to reduce the emission intensity by 20–25% from the GDP in 2020 compared [7] with 2005 level. Thus, the share of fossil fuel declined from 2009 to 2012 by adding the renewable sources into its power generation mix which is 12% as on 31st March 2012 and expected [3] to reach 17.12% in 2017. Fig. 3 shows the potential of renewable energy technologies; energy demand and supply in India for the year 2012. Hence, there exists a wide scope for reducing $CO_2$ emissions of the country by way of increased fuel substitution using of renewable energy sources and address [9] the growing energy demand.

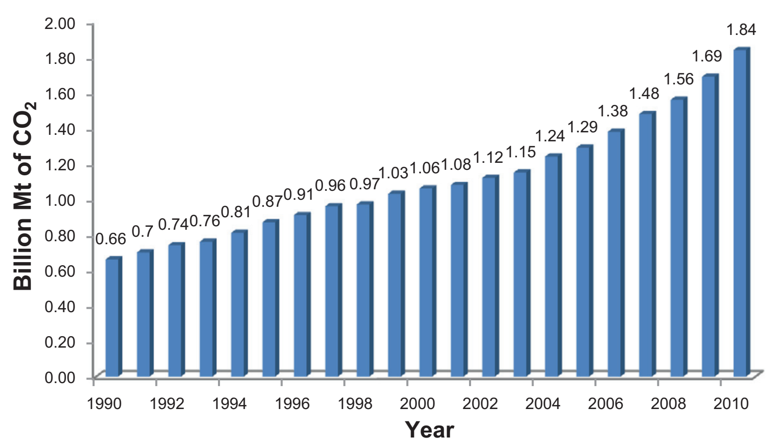


**Fig. 1.** The $CO_2$ emissions in India from 1990 to 2010.
*Source*: [7].

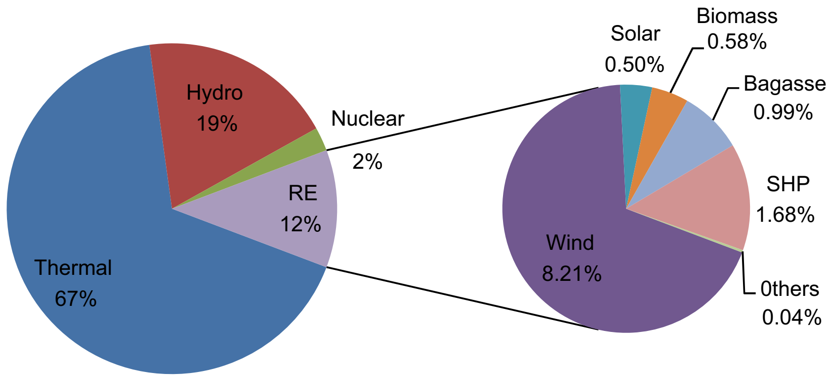


**Fig. 2.** Share of grid connected power capacity in India.
*Source*: [3].

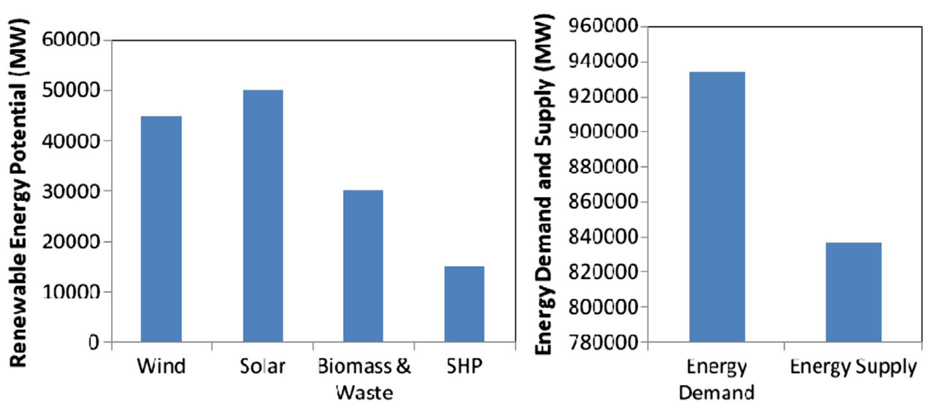


**Fig. 3.** Potential of renewable energy technologies, energy demand and supply in India.

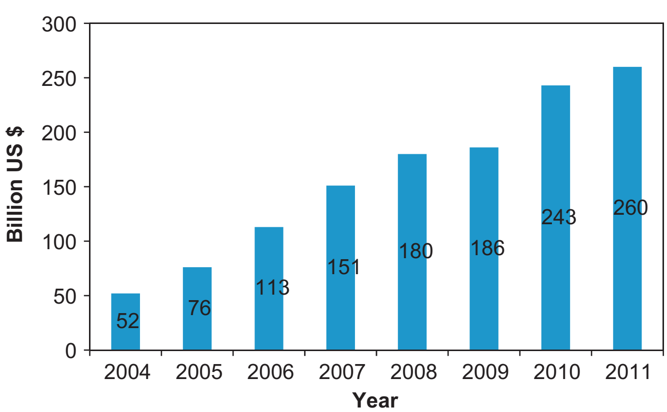


**Fig. 4.** Global investment in renewable energy sector.
*Source*: [2].

## 3. Status of clean energy investment

### 3.1. World scenarios

The continuing and expanding investment in antiseptic energy is an elegant option to mitigate worldwide $CO_2$ emissions and future energy challenges. However, the global renewable energy investment strongly increased almost five times from $52 to 260 billion [10] since 2004–2010, as shown in Fig. 4, although its market grew robustly in 2010 about an increase of 30%. An estimation by BNEF (Bloomberg New Energy Finance), revealed that, clean energy investment increased from $186 to 260 billion between 2009 and 2011 throughout the world. However, the total renewable (REN21, 2012 [15]) power capacity worldwide exceeded 1360 GW by the end of 2011.

According to BNEF [10] report, the worldwide investment in clean energy reached $260 billion in 2011 with an increase of 5% over 2010. The largest share of investment in 2011 about $136.6 billion in solar which is 36% higher compared than 2010. It is mainly caused by the fell down price of photovoltaic (PV) modules close to 50% in 2011. The clean energy investment of US in 2011 is $55.9 billion or 33%, China invested about $47 billion which is slightly higher than 2010 investment and in Europe it is increased to 3% from $100.2 billion primarily from solar.

### 3.2. Indian scenario

The new financial investment in renewable energy sector expands every year in developing countries. In India, clean energy [11] investment increased to $12.3 billion (BN) in 2011, which is 36% higher than 2010 investment as shown in Table 3. The largest growth obtained by a twofold increase of funding for grid connected solar projects from $2.7 to 4.8 billion since 2010–2011. The investment for wind energy increased from $3.8 to 5.9 billion from 2010 to 2011. Table 3 revealed that the investment in India after the COP15 in Copenhagen, 2009 it increased from $4.8 to 7.5 billion in 2010, and it robustly increased to $12.3 billion in 2011. According to REN21 2012 [15], India ranked fifth in the world for renewable energy investment as reported in Table 4 and accounted for 4% of global investment in clean energy. It caused by a number of factors, including Accelerated Depreciation (AD), tax breaks for wind projects, Jawaharlal Nehru National Solar Mission (JNNSM), launch of Renewable Energy Certificate (REC) and Renewable Purchase Obligation (RPO) schemes.

**Table 3**
Technology-wise investments by India between 2010 and 2011.
*Source*: [10,13].

| | New financial investment in 2010, $ BN | | | | New financial investment in 2011, $ BN | | | |
|---|---|---|---|---|---|---|---|---|
| Sector/asset class | Asset finance | Public markets | VC/PE | Grand total | Asset finance | Public markets | VC/PE | Grand total |
| Solar | 0.4 | 0.1 | 0.03 | 2.7 | 4.7 | 0 | 0.1 | 4.8 |
| Biofuel | 0.1 | 0 | 0 | 0.1 | 0.001 | 0 | 0 | 0.001 |
| Small hydro | 0.1 | 0 | 0 | 0.1 | 0.6 | 0 | 0.03 | 0.63 |
| Biomass and waste to energy | 0.41 | 0.29 | 0.09 | 0.8 | 0.9 | 0 | 0.03 | 0.93 |
| Wind | 3.3 | 0.5 | – | 3.8 | 5.5 | 0.2 | 0.2 | 5.9 |

Asset finance adjusted for re-invested equity.

**Table 4**
Countries with major new capacity investments with annual additions in 2011.
*Source*: [15].

| Rank | New capacity investment | Hydropower | Wind | Solar PV | Solar hot water/heat | Ethanol production | Biodiesel production |
|---|---|---|---|---|---|---|---|
| 1 | China | China | China | Italy | China | US | US |
| 2 | US | Vietnam | US | Germany | Turkey | Brazil | Germany |
| 3 | Germany | Brazil | India | China | Germany | China | Argentina |
| 4 | Italy | India | Germany | US | India | Canada | Brazil |
| 5 | India | Canada | UK/Canada | France | Italy | France | France |

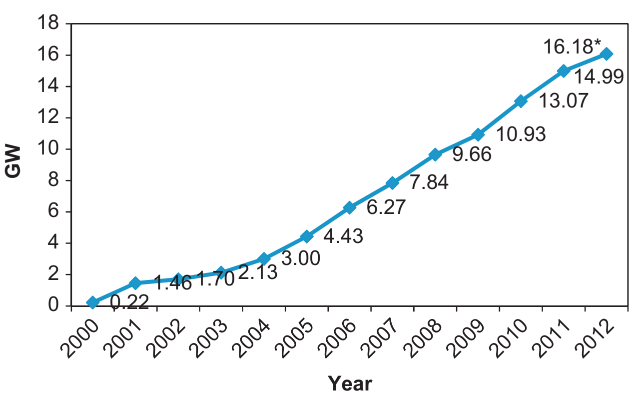


**Fig. 5.** Cumulative installed wind power capacity in India.
*Source*: [18].

**Table 5**
State wise wind energy status in India up to 31.01.2012.
*Source*: [17].

| State | Gross potential (MW) | Total installed capacity (MW) |
|---|---|---|
| Tamil Nadu | 14152 | 6613 |
| Maharashtra | 4584 | 2560 |
| Gujarat | 10645 | 2641 |
| Karnataka | 11531 | 1852 |
| Rajasthan | 4858 | 1830 |
| Madhya Pradesh | 1019 | 330 |
| Andhra Pradesh | 8968 | 213 |
| Kerala | 1171 | 35 |
| Odisa | 255 | – |
| Others | – | 4 |
| **Total** | **57,183** | **16,078** |

The asset financing for utility-scale projects is the prime clean [12] energy investment in India for about $11.70 billion in 2011. In addition, the venture capital (VC) and private-equity (PE) asset also made a strong come back with $0.36 billion in 2011, which is more than two times of 2010 asset. The wind and solar projects are the significant leader in the new investment. The wind sector attained a record of 2827 MW capacity in 2011 compared with 2140 MW in 2010. It helped India to attain third position globally for wind sector in terms of new [12] installations, behind China and US. The BNEF estimated that further 2500–3200 MW of wind capacity also added in 2012. Other than wind sector, the grid connected solar capacity also increased from 18 MW to 277 MW in 2010–2011. For the 11th plan, India targeted an addition of 12.4 GW of grid connected renewable energy and this leads to exceed 14.2 GW of installed capacity.

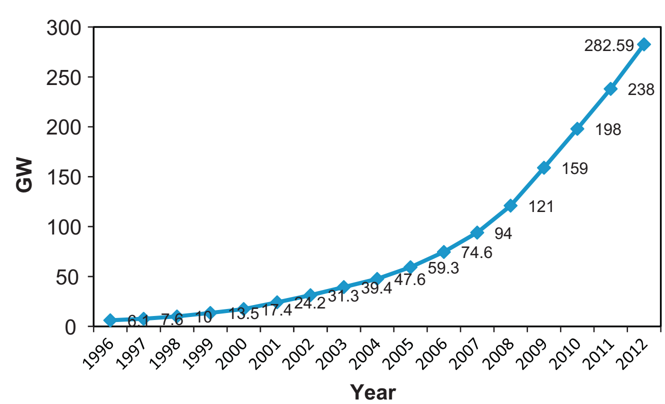


**Fig. 6.** Global installed wind power capacity (1996–2012).
*Source*: [15,16].

## 4. Clean technology-wise investment in India

### 4.1. Wind

The wind energy as a renewable technology considerably aids to abate $CO_2$ emissions instead burning of fossil fuel for electricity generation. The industrialized countries usually focused on wind energy for environmental concern. In many instances, it is a cost-effective substitute for fossil fuels. For the fuel replacement concern, a single 1 MW wind turbine will save 2000 t or more of $CO_2$ emissions per year [14]. India is one of the most hopeful countries for wind power development in the world. The

development of wind power in India began in 1990s and significantly increased in the last few years. India is the third largest investor in [16] wind energy market as shown in Table 4 from 2010 onwards, adding nearly 3 GW to reach an estimated capacity of 16.18 GW as on 31st January 2012 as illustrated in Fig. 5, due to that it maintains its fifth rank in new capacity investment.

The states of Tamil Nadu, Maharashtra, Gujarat, Rajasthan, Karnataka, Madhya Pradesh and Andhra Pradesh are high potential [17] wind concentration. Consequently, the potentially invested states for power generation through wind mills are Tamil Nadu (6613 MW), Maharashtra (2560 MW) and Gujarat (22641 MW) as shown in Table 5. The overall installed capacity of wind power about 16078 MW in 2012. It is estimated that 6000 MW of additional [17] wind power capacity installed by India in 2012. However, wind power accounts for 6% of India's total installed power capacity and currently it supports for 1.6% of the country's power supply.

The wind energy sector will carry out 24% of Indian energy demand in 2030 [18] while attracting \$10637.12 million investment for every year, and it is noteworthy that it would save 5.5 billion tonnes of carbon credits worth of \$80 billion. In the 11th plan, the government has proposed a financial outlay of \$44.79 million on research and development in wind energy sector, which targeted to create 42,000 green jobs in manufacturing, project development, installation, operation, maintenance and consulting.

Fig. 6 illustrated that the global installed wind power capacity increased by 20% in 2012 to approximately 282 GW by the year-end [15,16]. Thus, the global wind power market value expected to reach \$96.4 to 161.2 billion from 2011 to 2015. It would increase the share of wind power for the world 1.92% at the end of the year 2015.

### 4.2. Solar PV power

Solar energy is the most abundant resource in India and many regions receive 4–7 kWh $m^{-2}$ $d^{-1}$ of energy [19] with 250–300 sunny days annually, equivalent to more than 500 trillion kWh / year, which is sufficient to meet the current total primary energy demand. However, India forced to invest for converting solar energy into electrical energy. The PV system is a promising [20] source of electricity generation, fossil fuel saving and $CO_2$ emission reduction, even if current technologies applied. At an average solar radiation of 5.5 kWh $m^{-2}$, the net annual $CO_2$ mitigation potential of 1.8 kW solar PV pump estimated about 1860 kg and 2085 kg in the case of electricity [21] and diesel substitution respectively. The IEA, 2011 estimated the global $CO_2$ emission reduction by two [22] different scenarios. The first scenario restricted the $CO_2$ emission in 2050 at 2005 level with an estimated increase in PV capacity of 11 –600 GW from 2009 to 2050. In the second scenario, to reduce the global $CO_2$ emissions about 50% of 2005 level, the installed capacity of PV would exceed 1100 GW in 2050.

The launch of JNNSM in 2009 has given impetus to solar PV power in India. The targeted 20 GW of solar power in 2022 divided into 12 GW specifically [23] from ground mounted PV and CSP plants; 3 GW from the rooftop PV systems; another 3 GW from off-grid PV arrays in villages and 2 GW from other PV projects such as on telecommunication towers [24].

The Government of India invested \$38.31 million in the financial year 2011–2012 to expand PV power generation. In budget 2010–2011, Government of India has announced \$50.31 million to establish clean energy under JNNSM. It is an increase of \$32.59 million from the [23] previous budget as revealed in Fig. 7. Table 6 confirms the progress of PV plants in India under JNNSM a total of 32.37 MW of grid connected solar plants added in 2010–2011 and additional 955.63 MW added in 2011–2012 (Ministry of New and Renewable Energy) due to this the installed grid connected capacity increased to 988 MW. However, under JNNSM

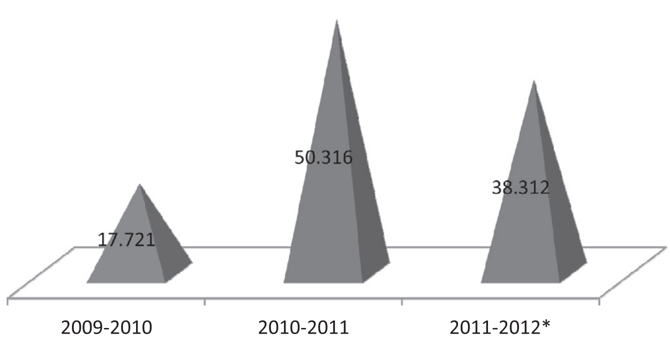


**Fig. 7.** Public investment in Solar PV for 2009–2012 (million US \$).
*Half of the financial year.

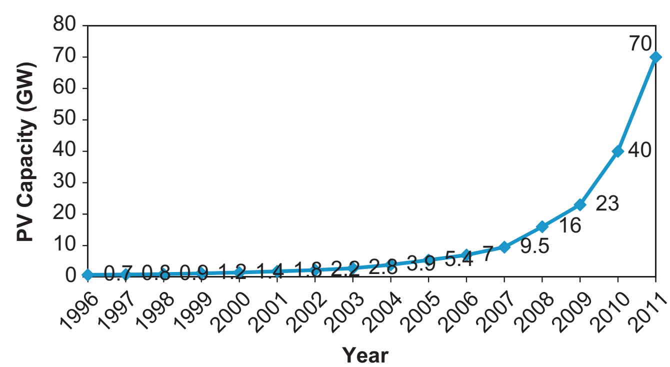


**Fig. 8.** Global installed PV power capacity (1996–2011).
*Source*: [15].

**Table 6**
Progress of solar PV grid connected capacity in India.
*Source*: [23,25].

| Year | Cumulative achievement (MW) |
|---|---|
| 2005–2006 | 2.74 |
| 2006–2007 | 2.92 |
| 2007–2008 | 2.12 |
| 2008–2009 | 2.12 |
| 2009–2010 | 9.13 |
| 2010–2011 | 32.37 |
| 2011–2012 | 988.00 |

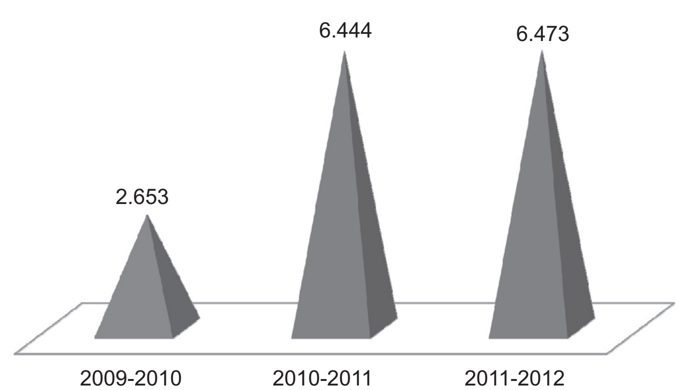


**Fig. 9.** Disbursement for solar thermal power plants in India by MNRE. (Million \$).
*Source*: [25].

scheme India aimed to mitigate 42 million tonnes of $CO_2$ at the end of 2020 by PV projects.

Globally the PV power generation technology is growing in more than 100 countries. An estimated capacity of 30 GW added worldwide in 2011 compared with existing capacity of 40 GW in 2010, as a result [16] the global total capacity increased to 70 GW as revealed in Fig. 8. The installed capacity increased more than 10 times compared with five years earlier, mostly dominated by EU (European Union) accounted for 80% of the world's total installed capacity of about 13.2 GW newly installed. Among the EU, the world's largest solar PV market by Italy lead with 57% share in global investment.

### 4.3. Concentrating solar thermal power (CSP)

There are large pessimistic environmental externalities caused in electricity generation due to the predominance of fossil fuels in the generation mix. The fossil fuel based power sector alone in India emit 0.82 $tCO_2$/MWh since 2008–2009 and 0.79 $tCO_2$/MWh from 2007–2008 [3]. Edenhofer et al. [24] accounted that each square meter of CSP concentrator surface is enough to avoid the 0.25–0.4 t of $CO_2$ annually. The majority of estimates fall between 14 and 32 g $CO_2$ eq/kWh for trough, central receiver tower, and Stirling and Fresnel systems.

In this context, it is imperative to develop and promote alternative power generation technology that can assure sustainability of the energy-environment system. As an option to reduce the fossil fuel consumption and $CO_2$ level, India investing more funds in the CSP (Concentrating Solar Power) technology, which included in the target of 20 GW by 2022 under JNNSM. Fig. 9 demonstrated that the invested amount of about $15.57 million to generate electricity through CSP technology during 2009–2012, with annual increment in investment.

Table 7 shows installed power plant in India from 2009 to 2012 through public and private partnership. The highest installed [25] capacity is in Rajasthan (420 MW) followed by Gujarat (351 MW) and Andhra Pradesh (50 MW). Additionally 140 MW of solar thermal power plant added at Mathania in Rajasthan by the state government and GEF (Global Environmental Facility). For this project, GEF approved a grant of US$ 40 million [26] and the Government of Germany provided a soft loan of DM (German Market Price) 116.8 million. The power plant [23] has the mitigation potential of 714,400 t of $CO_2$ per annum.

**Table 7**
Major solar thermal power plants in India by public and private sector.
*Source*: [25].

| Name of the developer | State | Capacity (MW) |
|---|---|---|
| Lanco Power | Rajasthan | 100 |
| Reliance Energy | Rajasthan | 100 |
| KSK Energy | Rajasthan | 100 |
| Godavari Power | Rajasthan | 50 |
| Corporate Ispat | Rajasthan | 50 |
| Aurum Renewable Energy | Rajasthan | 20 |
| ACME Telepower Limited | Gujarat | 46 |
| Adani Power Limited | Gujarat | 40 |
| Cargo Motors | Gujarat | 25 |
| Electrotherm Limited | Gujarat | 40 |
| Abengoa S.A., Spain | Gujarat | 40 |
| IDFC | Gujarat | 10 |
| KG Design Services Pvt. Ltd | Gujarat | 10 |
| SunBorne Energy Ltd | Gujarat | 50 |
| NTPC | Gujarat | 50 |
| Welspun Urja Limited | Gujarat | 40 |
| Megha Engineering | Andhra Pradesh | 50 |

### 4.4. Solar water heating systems (SWHS)

The fossil fuels such as coal for electricity production and gas for water heating both released large amounts of $CO_2$ into the atmosphere. However, by the use of renewable energy sources for water heating can cut the $CO_2$ emissions. From that, a 100 l capacity SWHS can replace [27] a residential electric geyser and save approximately 1500 units of electricity annually under Indian conditions. It estimated that the same amount of electricity generation from a coal based power plants would release 1.5 t of $CO_2$ into the atmosphere in every year. The conventional water heater replaced by the solar water heater a typical family can save 70–80% of electricity or fuel bills. It estimated that 100 l /day system (2 $m^2$ of collector area) can save approximately 140 l of diesel in a year. The reduction of pollution and preservation of environmental health is some of the co-benefits of this technology. Under JNNSM, India targeted to install 20 million $m^2$ of solar collector area by three phases by the end of 2020. From phase-I, the total installed capacity of SWHS about 6.98 million $m^2$ as illustrated in Table 8. Due to this India would mitigate 6.0 million -tonnes of $CO_2$ in 2020.

Globally, the demand for SWHS has been increasing significantly in the past few years, by an estimated capacity of 25–185 GW from 2010 to 2012 [15], excluding unglazed swimming pool heating. China continues to dominate the world market. There are no reliable figures for global investment in solar water heating system. However, based on installation the investment can be estimated at around $15 billion [28].

### 4.5. Biomass power

Around the countries in the world are investing profoundly in biomass technologies to attain energy security and reduce their fossil-fuel emissions and its related problems. Bio energy includes three sources viz., bio-gas, solid biomass and liquid bio fuel.

**Table 8**
Status of SWH systems in India.
*Source*: [29].

| Period | Cumulative target (Million $m^2$) | Addition during phase (Million $m^2$) |
|---|---|---|
| Phase I (2010–2013) | 7.0 | 6.98[a] |
| Phase II (2013–2017) | 15.0 | 8.0 |
| Phase III (2017–2022) | 20.0 | 5.0 |

[a] (Achieved as on 31.03.13).

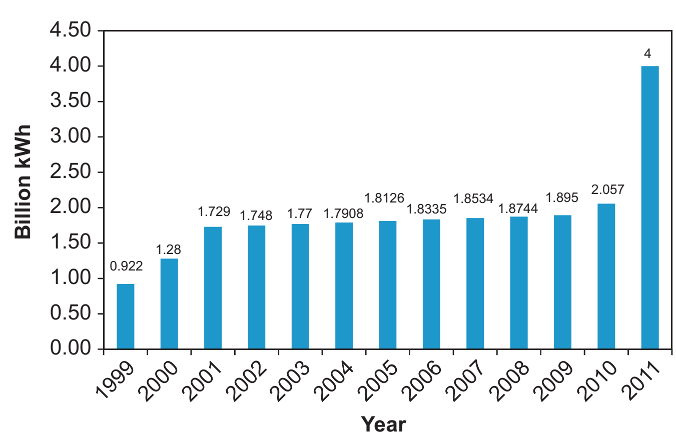


**Fig. 10.** Net electricity generation in India from biomass and waste.
*Source*: [32].

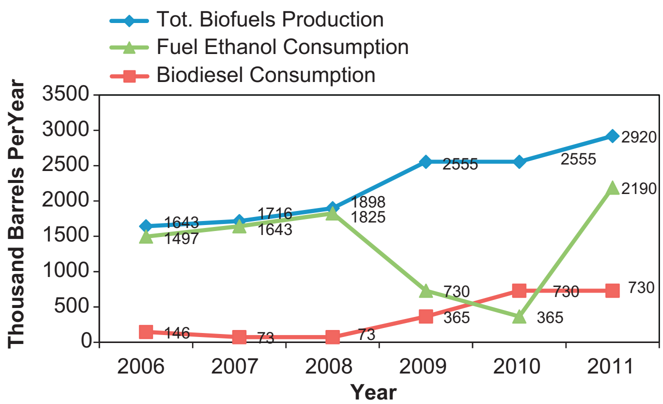


**Fig. 11.** Total bio fuel production and consumption of India.
*Source*: [32].

**Table 9**
State wise production of ethanol by sugar mills in India.
*Source*: [34].

| States | Production (Thousands Mt) | | |
|---|---|---|---|
| | 2007–2008 | 2008–2009 | 2009–2010 |
| Maharashtra | 414 | 350 | 267 |
| Punjab | 249 | 296 | 263 |
| Tamil Nadu | 119 | 120 | 135 |
| Uttar Pradesh | 734 | 540 | 358 |
| Uttarakhand | 116 | 69 | 39 |
| Andhra Pradesh | 61 | 127 | 127 |
| Bihar | 14 | 30 | 16 |
| Gujarat | 63 | 67 | 40 |
| Haryana | 40 | 32 | 32 |
| Karnataka | 157 | 163 | 172 |
| India | 1967 | 1795 | 1450 |

The bio energy derived from biomass, bagasse, forestry, agro residue and agricultural wastes, and cattle cake. The cattle population of India compared [30] with world level is 28%. Thus, the potential of energy from bio-gas generation stands for 17,350 million m$^3$. In recent years, the interest in using woody biomass has increased owing to rich forest biomass potential of India. The country endowed with vast forest cover about 21.02% of the geographical area [31]. The non forest cover excludes scrub and estimated to cover an area of 77.72%. Thus, India has mainly focused 77.72% of non forest cover for energy production. Against the estimated potential of 18,000 MW, the installed capacity of (MNRE) biomass plants in India is 2664 MW at the end of 2011. These plants are in Uttar Pradesh (592 MW), Tamil Nadu (488 MW), Maharashtra (403 MW), Karnataka (365 MW), Andhra Pradesh (363 MW), Punjab (74 MW), Rajasthan (73 MW), Haryana (35 MW), West Bengal (16 MW), Uttarakhand (10 MW) and Madhya Pradesh (7 MW).

Nearly, 12 million family-sized bio-gas [25] plants can be installed in India out of this 4 million family size bio-gas plants in operation that resulted in saving 120000 t of fuel wood and thereby preventing 60000 t of carbon emission. Furthermore, 1300 MW of extra energy can be generated by using industrial waste water from distilleries. Under distributed/grid connected power generation, the MNRE has installed 73 projects with a total capacity of 451 kWh. Fig. 10 showed the annual increment of entire installed grid-connected biomass and bagasse based power generation capacity from 1999 to 2011, achieved the capacity of 0.92–4.0 billion kWh.

Globally biomass power capacity increased from 66 GW to almost 72 GW at the end of 2011. Biomass heat assets are expanding steadily, particularly in Europe and also in the United States, China, India, and elsewhere. Asset financing for biomass (including waste-to-energy) downed 10% to $10.2 billion in 2010. The sector continued to be plagued by feedstock supply challenges and uncertainty over future feedstock prices.

**Table 10**
Geothermal potential of different provinces of India.

| Province | Surface temperature (°C) | Reservoir temperature (°C) | Heat flow (mW/m$^2$) | Thermal gradient (°C/km) |
|---|---|---|---|---|
| Himalaya | $>90$ | 260 | 468 | 100 |
| Cambay | 40–90 | 150–175 | 80–93 | 70 |
| West Coast | 46–72 | 102–137 | 75–129 | 47–59 |
| Sonata | 60–95 | 105–217 | 120–290 | 60–90 |
| Godavari | 50–60 | 175–215 | 93–104 | 60 |

**Table 11**
Current geothermal projects in India.
*Source*: [25].

| Geothermal field | State | Estimated reservoir temperature in (°C) | Reservoir depth (m) | Plant capacity (MW) |
|---|---|---|---|---|
| Puga | Jammu & Kashmir | 240 | 200 | 3.0 |
| Tattapani Sarguja | Chhattisgarh | 120–150 | 200–200 | – |
| Tapoban Chamoli | Uttarakhand | 100 | 430 | – |
| Badrinath Chamoli | Uttarakhand | 150 | – | – |
| Cambay Garben | Gujarat | 160 | 1900 | 10.0 |
| Surajkund Hazaribagh | Jharkhand | 110 | – | – |
| Manikaran Kullu | Himachal Pradesh | 110 | – | 60.0 |
| Kasol Kullu | Himachal Pradesh | 110 | – | – |
| Khammam | Andhra Pradesh | – | – | 60.0 |

### 4.6. Bio fuels

India is keen on reducing petroleum products and encouraging bio fuel to fulfill its energy demand and reduce $CO_2$ emission. Fig. 11 shows the [32] bio fuel production in India increased from 1643 to 2920 thousand barrels per year for the consecutive year of 2006–2011. However, the use of bio fuels for transportation offers alternative to petrochemical products, which can help to mitigate the $CO_2$ level. Globally motor vehicles alone emit 70% of CO emission and 19% of $CO_2$ emission [33]. For that reason, India decided to cut down its dependence on diesel and use of non-edible based oil as fuel. From Fig. 11 against the production, the consumption of ethanol increases from 1497 to 1825 thousand barrels during 2006–2008 and its consumption decreases from 1825 to 730 thousand barrels because, usage of biodiesel increased from 73 to 730 thousand barrels for the consecutive years. The Indian government approved its national biofuel policy to target 20% of blended diesel and petrol by the end of 2017. As a result, the demand for biodiesel is increasing every year. Table 9 shows the state wise production of ethanol from sugar industries. The state Maharastra is the topper for the production of ethanol from 2007 onwards. Under the bio fuel policy, the government proposes

**Table 12**
Status of grid-connected SHP power in India.

| Position | Five year plan | Capacity (MW) |
|---|---|---|
| Achieved | 9th plan (2002–2006) | 1438* |
| | 10th plan (2002–2007) | 520** |
| In progress | 11th plan (2007–2012) | 1400** |
| Anticipated | 11th plan (2007–2012) | 3358* |
| Targeted | 11th plan (2008–2012) | 6500* |

* Cumulative installed capacity.
** Addition during the plan period [9].

a minimum support price for non-edible oilseeds. This policy framework ought to see the massive investment in the sector. It caused, the current investment reached $0.2 billion and which is less than 10% of the total financial investment in clean energy in 2009 [13]. India targeted [35] to produce 10% of 1.08 billion litres of ethanol from molasses for the year 2011–2012 and the end of 2017, 20% of 0.24 billion litres of biodiesel targeted.

Globally the bio fuel sector experienced a 19% drop in asset finance, to $4.7 billion. This is one quarter of the $20 billion of asset financing [28] that the sector secured in 2007 and less than one-third of the 2008 ($16 billion). The less growth attained by lower crude oil prices and uncertainty feedstock supplies in 2010.

### 4.7. Geothermal power and heat

"Geothermal energy" is clean, reliable, and home-grown [36]. This energy can be used effectively in both on and off-grid developments and is especially useful in rural electrification schemes. Its usage covers a large range of power generation to direct applications like space heating, cooking, bathing and swimming, industrial process heat, agricultural drying, greenhouse and open ground heating, aquaculture pond heating, etc.

Now at least 78 countries [37] generating power with a total capacity of 10.7 GW, upon that 88% of it generated [15] by the US, Philippines, Indonesia, Mexico, Italy, New Zealand, and Iceland with an investment of over $500 million excluding Iceland during 2005–2009. The regional wise [38] investments for direct usages, electric power projects and research and development are:

- 33% in Asia by 7 countries,
- 27% in America by 8 countries,
- 21% in Europe by 24 countries,
- 15% in Oceania by 2 countries, and
- 4% in Africa by 5 countries.

The geothermal potential in India is about 10600 MW from the five [25] provinces as shown in Table 10. Further more than 300 hot spring locations identified by the Geological Survey of India in 2000. India installed first generation based geothermal power plant in Khammam district, Andhra Pradesh with a capacity of 25 MW with an investment cost of $64.66 million. The plant producing power from non-polluting sources make it an attractive carbon credit project. This is significant against the growing global challenges of global warming and climate change.

Table 11 illustrated the investment of geothermal [25] field by public and private partnerships are Panx Geothermal, LNJ Bhilwara, Tata Power, Thermax, NTPC, Avin Energy Systems and GeoSyndicate Power Private Limited. The geothermal energy in India compared with remaining parts of the world is moving at a snail's pace due to the problems associated with project development and finance. However, the potential of this energy resource is immense which compared with worldwide potential. It needs strong support from the government as financial incentives to make use of its potential.

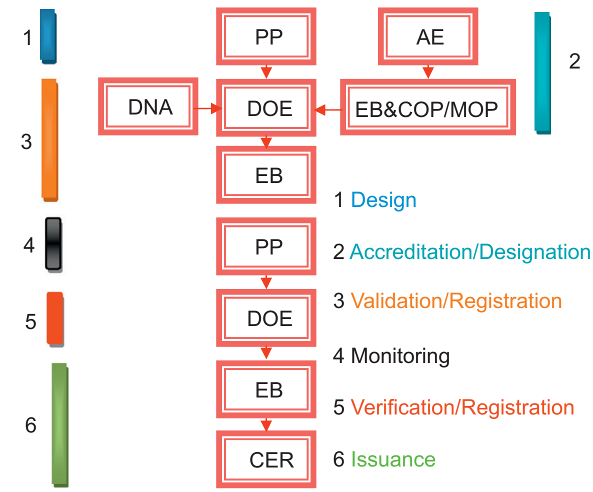


**Fig. 12.** CDM projects in India for host country approval. PP: project proponents, EB: executive board, DOE: designated operation entities. DNA: designated national authority, AE: applicant entity, CER: certified emission. Reduction, COP/MOP: conference of the parties and meetings serving as meeting of the parties to the Kyoto Protocol.

**Table 13**
Sector wise CDM projects in India.
*Source*: [39].

| Name of sector | No. of projects | CER up to 2012 |
|---|---|---|
| Energy efficiency | 455 | 217,421,223 |
| Forestry | 10 | 10,411,540 |
| Fuel switching | 81 | 61,281,198 |
| Industrial process | 95 | 111,780,559 |
| MSW | 35 | 11,526,169 |
| Renewable | 547 | 129,658,846.39 |
| Renewable (Biomass) | 355 | 91,322,012 |
| **Total (No. of projects)** | **1578** | **633,401,547.39** |

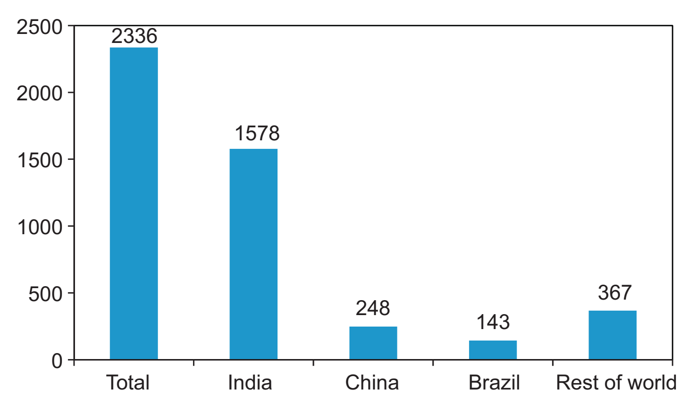


**Fig. 13.** Number of CDM projects in India and World [39].

### 4.8. Small hydro power plant

Small hydro power (SHP) is a renewable, economic, non-polluting and environmentally benign source of energy. Small and mini-hydro power help to provide energy in remote and hilly areas, where an extension of the grid system is uneconomical and would reduce GHG and local pollutant emissions, is one of the thrust areas of the Government of India. Power generated from hydro sources increased due to independence from fuel price developments and carbon emission costs, and additional revenue [24] from carbon credits.

**Table 14**
Plan wise growth of renewable power generation capacity (MW).
*Source*: [25].

| Resources | By the end of 9th plan (1997–2002) | By the end of 10th plan (2002–2007) | By the end of 11th plan (2007–2012) | For ongoing 12th plan (2012–2017) (as on 31.03.2013) |
|---|---|---|---|---|
| Wind power | 1667 | 5415 | 17,582 | 19,051 |
| Small hydro | 1438 | 520 | 3358 | 3632 |
| Bio-power | 368 | 750 | 3218 | 3698 |
| Solar power | 2 | 1 | 53 | 1686 |
| Total | 3475 | 6686 | 24,211 | 28,067 |

**Table 15**
$CO_2$ mitigation potential of grid connected renewable power generation system.

| Year | Installed capacity (MW) | Installed capacity (TWh) | Baseline $CO_2$ (kg/kWh) | Mitigation potential million tonnes of $CO_2$ |
|---|---|---|---|---|
| 1992 | 32 | 0.28032 | 0.86 | 0.27 |
| 1997 | 902 | 7.90152 | 0.86 | 7.49 |
| 2002 | 1658 | 14.52408 | 0.86 | 13.77 |
| 2007 | 7761 | 67.98636 | 0.86 | 64.45 |
| 2012 | 24,503 | 214.6463 | 0.86 | 203.48 |
| 2017 | 54,503[a] | 477.4463 | 0.86 | 452.61[a] |

[a] Targeted mitigation potential.

**Table 16**
The $CO_2$ mitigation potential from different technologies (Million Tonnes of $CO_2$).

| Resources | By the end of 9th Plan (1997–2002) | By the end of 10th plan (2002–2007) | By the end of 11th plan (2007–2012) | For ongoing 12th plan (2012–2017) (as on 31.03.2013) |
|---|---|---|---|---|
| **Wind power** | **13.84** | **44.97** | **148.02** | **158.21** |
| **Small hydro** | **11.94** | **4.32** | **27.89** | **30.16** |
| **Bio-power** | **3.06** | **6.23** | **26.72** | **30.71** |
| **Solar power** | **0.02** | **0.01** | **0.85** | **14.00** |
| **Total** | **28.86** | **55.53** | **203.48** | **233.08** |

The SHP generations classified into three categories in India by CEA (Central Electricity Authority of India) are micro (100 kW or less), mini (100–2 MW) and small (2 –25 MW). As most of the potential, about 24% lies in the inaccessible Himalayan region such as Himachal Pradesh, Uttarakhand, Jammu and Kashmir and Arunachal Pradesh, the MNRE charged the responsibility to develop small hydro power plants up to 25 MW.

In an innovative approach, the Indian Renewable Energy Development Agency (IREDA) started financing private sector to develop SHP projects with the aid of World Bank Energy Management Assistance program. The World Bank offered $70 million to IREDA to support SHP projects on irrigation dams and canals for a target capacity of 100 MW and additional 33 SHP project sanctioned with an aggregate capacity of 113 MW in the year 2000. Following the successful development of SHP projects in India, the World Bank offered second line aid worth of $110 million to IREDA in 2009.

The SHP development during the 9th plan, achieved 1438 MW capacity although, this progress downed 520 MW during the 10th plan as shown in Table 12. In addition, the ongoing 11th plan aimed to install 1400 MW capacity. The development of SHP in 2010 reached 2.9 GW under various stages of 938 projects. As reported by CEA, India ranked at six worldwide for total hydropower capacity with an existing capacity of about 40 GW in 2012 whereas SHP potential is 15386 MW in 5415 identified sites.

## 5. Status of CDM in India to mitigate $CO_2$ level

The Kyoto Protocol of United Nations Framework Convention on Climate Change (UNFCCC) provide Certified Emission Reductions (CERs) to projects which are reducing or avoiding $CO_2$ emissions on the basis of conditions of additionality, permanence and leakage under its CDM (Clean Development Mechanism). It provide hope to the industrialized (Annexure-I) countries with higher $CO_2$ emissions to invest in developing (Non Annexure-I) countries with lower $CO_2$ emissions in CDM projects and thereby earn the CERs, and it would benefit together, the guest and host. Though India in the Non Annexure-I countries, frequently criticized for its mounting GHG emissions, especially $CO_2$, without weighing its massive population. Therefore, now India voluntarily committed and focusing on clean investments with lesser $CO_2$ emissions. The renewable energy sector that receives considerable portion of the clean investments to reduce the $CO_2$ emissions from fossil fuel based energy generation. Fig. 12 shows the project proposal should establish the following order to qualify the CDM project in India. Under the project proposal, the sector-wise CDM projects illustrated in Table 13, including biomass based cogeneration, industrial process heat, municipal solid waste, forestry, and energy efficiency of the system. The highest number of CDM projects in India about 1578 compared with China (248), Brazil (143) and the rest of the world (367) as shown in Fig. 13. The projects can help Indian firms rake in money from trading carbon credits and to mitigate the $CO_2$ level.

## 6. Renewable energy growth with governmental policies

Currently India is fast becoming one of the world's most attractive markets for Renewable Energy investments. India's rise has been due to the effective policy and regulatory support for development of Renewable Energy Technologies (RETs). Various policy measures such as Accelerated Depreciation (AD), Feed-in-Tariff, Generation Based Incentives (GBI), Renewable Purchase Obligations (RPO) and Renewable Energy Certificates (REC) have helped in the rapid growth of Renewable Energy deployment in the country.

In the mid 1990s, tax incentives kick-started the Indian renewable energy economy, leading to significant investment into wind parks by Indian taxpayers. From 2007 onwards, India moved towards Generation Based Incentives (GBI) and Feed in Tariffs (FiT) for wind and solar. The implementation of these two polices has helped for the tremendous growth of wind power installed capacity in the country. Due to that at the end of 11th plan, the installed wind power capacity reached about 17582 MW. This addition of wind power capacity taking the total installed renewable energy capacity at the end of 11th plan is to 24211 MW. Plan wise growth of renewable power in the country since the beginning of the 9th Five Year Plan is given in Table 14.

The Jawaharlal Nehru National Solar Mission (JNNSM), which came into effect in 2010, is the first scheme that supported a renewable energy source across the country and based on a preferential Feed in Tariff. The Renewable Purchase Obligation (RPO) amended in January 2011. Most of the State Electricity

Regulatory Commissions (SERCs) have specified percentage of RPOs. The tariff policy has been amended to ensure that 0.25% and 3.0% electricity originates from solar electricity by 2013 and 2022. In addition, the RPO system will help India to complete the transition from installed capacity-based to more effective generation-based incentives. It will also be a significant step towards a free market for renewable energy by placing wind, biomass and small hydropower in direct competition with each other.

In addition, the launching of Renewable Energy Certificate (REC) helps in the creation of a pan-India renewable energy market. A large domestic manufacturing base has been established in the country for renewable energy systems and products. Companies investing in these technologies are eligible for fiscal incentives, tax holidays, and depreciation allowance apart from the remunerative returns for the power fed into the grid. Further, the government is encouraging foreign investors to set up renewable power projects with 100 percent foreign direct investment. Table 14 shows from the beginning of 12th five-year plan the renewable energy sector was witness to tremendous changes in the policy with accelerated and ambitious plans to increase the contribution of solar power in the energy mix of the country.

## 7. $CO_2$ mitigation by renewable energy investment

Increasing the use of renewable energy sources often substitutes fossil fuel based energy sources that have relatively higher $CO_2$ emissions. The estimation of the mitigation potential of renewable energy sources is necessary to highlight the cleaner nature of investment made in this sector. The $CO_2$ mitigation contributed by renewable energy sector estimated by using the baseline emissions of the fossil fuel based energy generation. Further, the amount of $CO_2$ mitigated by renewable energy technologies depends on the $CO_2$ intensity of the energy mix along with the assumption of renewable energy technologies are substitutes for fossil fuels.

Table 15 revealed that the $CO_2$ mitigation potential of grid connected renewable power generation system in India obviously increased with investment. The current mitigation potential of the system is 203.48 million tonnes of $CO_2$, and expected to reach 452.61 million tonnes of $CO_2$ in 2017 with the projected investments in renewable energy sector.

## 8. Conclusion

The current research revealed that India is paramount, after China, for clean business investment. The clean renewable includes wind, solar, biomass and small-hydro projects. The major portion of investment in India made in wind energy sector. The investment in wind energy sector grew at 17% from $2.2 billion to $2.6 billion. The present study identified that India has witnessed substantial growth of renewable energy technologies during the last two decades. This growth can be attributed by the participation of private sector, as a consequence of favorable policy frameworks and investment options and opportunities available for such technologies. Table 16 shows the plan wise mitigation potential of $CO_2$ from different renewable energy technologies. It revealed that at the end of 11th plan, the mitigation potential of $CO_2$ is 203.48 million tonnes of $CO_2$, which is 27% higher than 10th plan. Currently, the investment made in the renewable energy sector leads to mitigation of 233.08 million tonnes of $CO_2$. However, much more remains to be done in harnessing the true potential of renewables in the country and effectively reduce $CO_2$ emissions. However, enormous potential identified in renewable energy sector with favorable $CO_2$ mitigation the government is compromising with limited financial resources. The current policy environment has yielded significant results in creating a large and diverse renewable energy market. However, policy efforts need to be taken to the next level to encourage a massive scale-up of renewable technologies, to increase the share of renewable energy in the overall energy mix, and an effective way to $CO_2$ mitigation.

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